nent north of 50° north latitude and moved eastward at or north of the Canadian boundary. As a result the warmest February, perhaps in a century, was experienced in the United States. With the exceptional heat there was much dryness and it is perhaps not far from the truth to ascribe the beginning of the drought to the disturbed condition of the general circulation that set in in that month. The succeeding months, March to June, were not especially dry except in rather small areas; North Dakota, for example had but 11 per cent of its normal rainfall in March. The most noticeable phenomenon was the breaking down of the cyclonic part of the secondary circulation and perhaps in one or two months the intensification of the circulation induced by anticyclones. The latter was especially noticeable in the piedmont sections of the States south of the Pennsylvania line. In these States it was doubtless the largest single factor contributing to the failure of the rains.

Anticyclones mostly from the Hudson Bay region drifted southward and settled over the Carolinas, Virginia, and Maryland thus insuring to those States at least a week of uninterrupted sunshine before the high pressure would pass away; moreover, the presence of high pressure over the Atlantic off the Carolina coast with the wedge-shaped front extending westward across the Appalachians doubtless diverted the paths of cyclonic storms approaching from the West into a more northerly course, thus withholding from the Virginia-Maryland region the rains that were received by States farther westward. Still another condition the reason for which is not known persisted, viz, cyclonic storms moving northward along and a short distant offshore failed to give rain in coastal States until the New Jersey coast was reached.

In September the weather control was mostly anticyclonic with no cyclones of importance, except, possibly on two occasions, the 23d and 26th; on the first named a cyclonic storm with circular isobars and central pressure down to 29.10 inches moved north-northeast from Montana to Manitoba with a further fall of pressure to 29.05 inches. A secondary from this cyclone developed over Colorado and moved thence to Wisconsin central pressure falling to 29.16 inches. This storm was attended by considerable precipitation in the Lake region and Ohio Valley, but the center of the cyclone continued to move northward to Hudson Bay in the ensuing 24 hours with no rain in the Carolinas and thence to southern New England. High pressure followed closely in the wake of the cyclone.

CONCLUSION

The secondary circulation, especially that branch which is associated with air movement about cyclonic systems, became weak and disorganized during the spring and early summer months of 1930. By midsummer a blanket of warm surface air had developed over the great interior valleys extending from the Gulf of Mexico to the Canadian border in which the normal temperature gradient with latitude had been destroyed.

Beginning with the turn of the season in September, when the transfer of polar air equatorward normally sets in, the chief weather control as between cyclones and anticyclones passed definitely to the anticyclones. In September, 1930, anticyclones from the Hudson Bay region moved south-southeast and merged with the semi-permanent high pressure over the Atlantic some distance east of the Carolina coast. In that position they served as a buffer to prevent cyclonic systems from moving up the Ohio Valley and spreading across the Appalachians into Atlantic coast States. The effect of this control was to augment the tendency of the dry weather to maintain the status quo in the piedmont sections of Atlantic coast States where drought still endures.

WEATHER CONDITIONS AS FACTORS IN THE FILTRATION OF THE WATER SUPPLY AT DETROIT, MICH.[1]

By BERT HUDGINS

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Weather conditions are the most important single factor necessitating variations in the purification process in the Detroit water supply. Winds reaching from 20 to 30 miles per hour, for a few consecutive hours, tend to stir up the waters of shallow Lake St. Clair, lap the shores and gather pollution from them and their populous hinterland, with the result that at the filtration plant there is an increase in the turbidity, increased bacteria, and likewise increased *B. coli*. Thaws in winter cause ice to break loose from shores and streams to swell with polluted waters, bringing great quantities of sewage to the lake and water intake. Rainstorms flush out tributaries to Lake St. Clair, and in the spring, the break-up of ice in the upper Lakes produces much pollution. The intake for the water supply is located at the head of Belle Isle, near the outlet of Lake St. Clair. The area of Lake St. Clair is 460 square miles; no place in it is more than 22 feet deep, and therefore it is easily stirred up. Numerous tributaries drain to it from a populous land along its borders and the St. Clair River. The largest of these tributaries are Fox and Conners Creeks, entering a short distance above the intake. These creeks have given cause for great pollution in the past, but now their flow is intercepted and sent southward under Jefferson Avenue, paralleling the river, and making exit to the river some 4 miles below the intake. (Figs. 1 and 2.)

Evidences of the influences of the various conditions of weather can be seen best when charted with filtration records. The following study will show in the order named a case of the influence of the wind, the influence of wind when the lake is ice covered, the influences of wind and back flow of the river, rainstorms, thaws, and lastly a case of the influences of a combination of weather conditions on the filtration process.

Wind as a factor influencing filtration is illustrated by the storm of December 8, 1928. This storm developed from a well-marked LOW which passed eastward as most low-pressure areas do in the United States. This particular low passed slightly north of Michigan, and on the weather map of December 8, was centered about 200 miles north of Georgian Bay and was well-developed. A fairly well marked HIGH was located at the same time in Texas, and as is the case when well developed HIGHS and LOWS are so close to each other, the pressure gradient was steep (1.7 inches difference). The wind velocity reached a maximum of 60 miles per hour from the southwest at Detroit during the early morning of December 8. The direction shifted to the west for a few hours near midnight on December 8, but returned to the southwest,

[1] This article is an excerpt from a doctor of philosophy dissertation submitted at Clark University, Worcester, Mass. in April, 1930.

where it remained with a velocity of about 20 miles per hour until December 11. This high wind velocity lashed the river and lake waters into a billowy sea. The *Tashmoo*, Belle Isle ferryboat, was broken loose from its winter moorings near the foot of Woodward Avenue, and blown upstream 3 miles and lodged against the Belle Isle Bridge. The northeast-southwest trend of the river here facilitated the movement. The filtration plant recorded rapid rises in turbidity and bacteria almost immediately following the high wind. (See fig. 3.) *B. coli* counts rose to the unprecedented number of 100,000 per 100 cubic centimeters of sewage, and the application of alum was increased one-third for the five days beginning with December 7.[1] Since many sewers empty into the river a short distance from the intake, it is evident that much of this sewage, perhaps in the form of a greasy surface film reached the intake. When the cost of extra alum used as a result of this storm is calculated, it is found to amount to about $550. This expense does not consider extra chlorine, the shortening of the rate of filter run, and consequent increased cost of operation thereby, to say nothing of extra labor and worry of officials and laboratory men. The weather disturbance of December 8, considered as a 5-day storm as charted, cost the city $550 in alum alone.

Wind, when the lake is covered with ice, has little influence in the filtration process. If the ice cover is unbroken on Lake St. Clair it prevents wind contact with the water, and prevents increased turbidity and bacteria counts at the filtration plant. The windstorm of February 19, 1928, illustrates this fact. (Fig. 4.) Though a velocity of 35 miles per hour was reached and maintained above 20 miles per hour for 12 hours on the 19th, no increased pollution seems to be coincident with it. Weather records show that for nine days of the month of February preceding the 17th, there was a mean temperature of 32° F. or above, but that after February 19, the mean daily temperature was as low as 17° F. for several days. It is probable that these high preceding temperatures and resultant melting is a better explanation of bacteria and *B. coli* irregularities during this storm than increased wind velocity.[3]

Changes in air temperature and water "turnover" as factors in the bringing of turbidity, plankton, and pollution to the water supply are illustrated by the storm of November 29, 1928. (Fig. 5.) In it there is a close correlation of wind velocity and turbidity increases, as well as alum dose, bacteria, and *B. coli* on November 30 and December 1. However, the high *B. coli* shown on the early morning of November 30 is not explained thus, for no high wind velocity preceded it. It had not rained for one week previous, but the mean daily air temperature was 26° and 28° F., respectively, on November 25 and 26. By observing water temperatures it was noted that they fell to 39° F. on November 26, and except for December 16 and 17, remained below 39° until the end of the year. Since 39° F. is the temperature of the greatest density of water, it is likely that this is

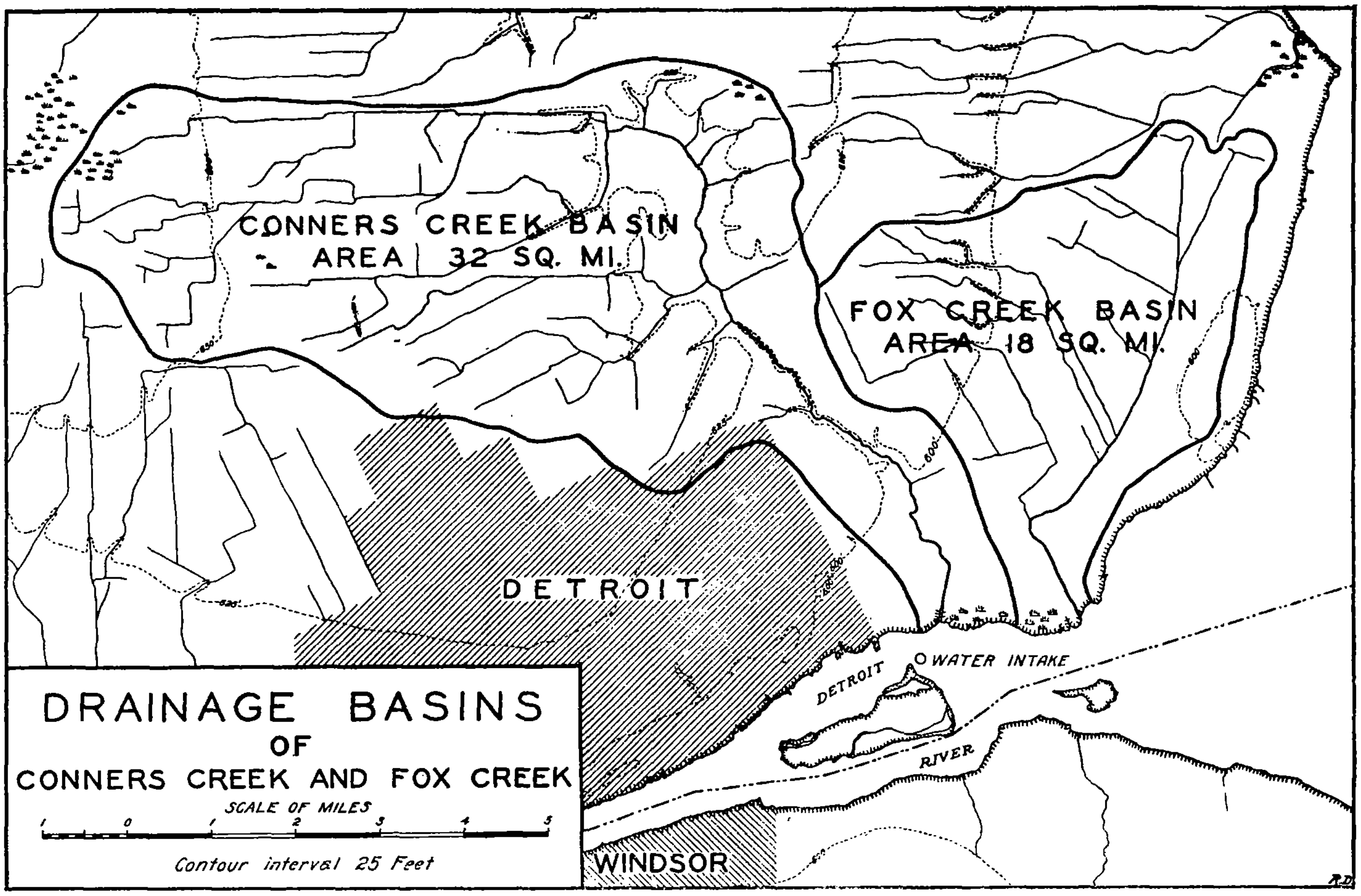

FIGURE 1.—The Fox Creek and Conners Creek Basins. Notice the nearness of the outlets of Fox and Conners Creeks to the water intake, Peche Isle, and the United States-Canadian international boundary

[1] Alum, aluminum sulphate, costs the city $1.25 per 100 pounds and is the largest single cost factor in filtration. A small carload is used daily (30,000 pounds).

[3] All weather data and filtration records are taken directly from the offices of filtration and the weather bureau in Detroit.

the water "turnover" period in Lake St. Clair, at which time it would naturally show an erratic record of bacteria because of the opportunity of these being brought from bottom to top, and exchanged about in this process. General plankton, bacteria, and *B. coli* increases come at this period of the year.

The back flow of the Detroit River is sometimes accomplished by winds, and the result is a difficult problem in the purification of the water supply at these times.

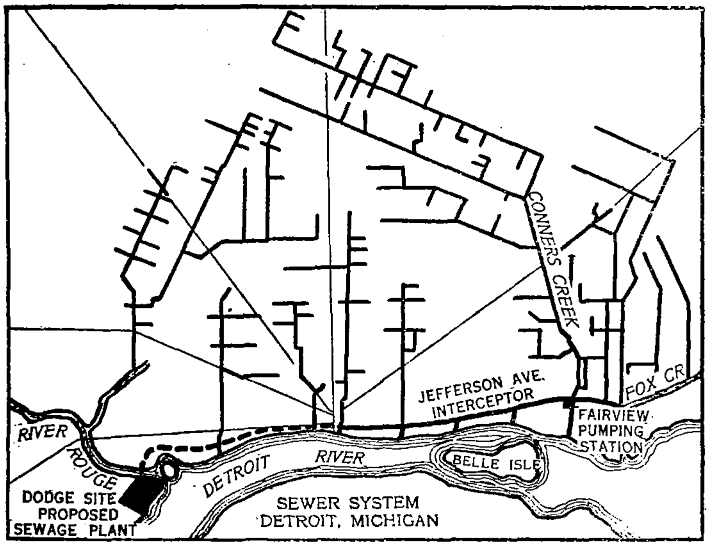

FIGURE 2.—The location of important sewer mains in Detroit. Notice the large Conners Creek system, which has resulted from the natural development of a sewer system in the Conners Creek Basin. (See also Fig. 1.) This large drainage area empties into the upper Detroit River near the waterworks intake, but it is partially intercepted now

By mixing the water and stirring up turbidity and pollution from the shores of the Detroit River and

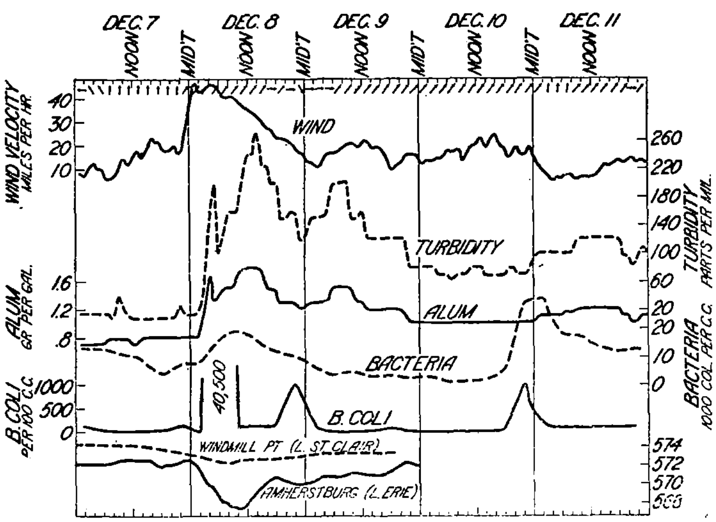

FIGURE 3.—Unprecedented *B. coli* counts of 100,000 per 100 cubic centimeter resulted from high wind velocities on Dec. 8, 1928. At midnight on the 7th, Lakes St. Clair and Erie were almost at equal levels. Increased alum was applied but turbidity did not serve as an indicator. In this case filter men realized from experience that high wind velocities would bring pollution, so additions of alum to facilitate coagulation and settlement, were made before contamination came

Lake St. Clair, and bringing this to the intake for the Detroit water system, the wind sometimes causes a back flow of the river which may give a great deal of impurity to the water at the location of the intake. Four conditions make this back flow possible: (1) Many sewers outlet into the river below Belle Isle Bridge; (2) the water intake is located at the head of the river and not far out into Lake St. Clair; (3) the average difference in elevation between Lake Erie and Lake St. Clair is 3½ feet, though they are 20 miles apart;[4] and (4) with strong enduring easterly winds, Lake Erie with its long east-west extent piles up water at its western end and thus checks the flow of the Detroit River, and raises the water level higher than that in Lake St. Clair.

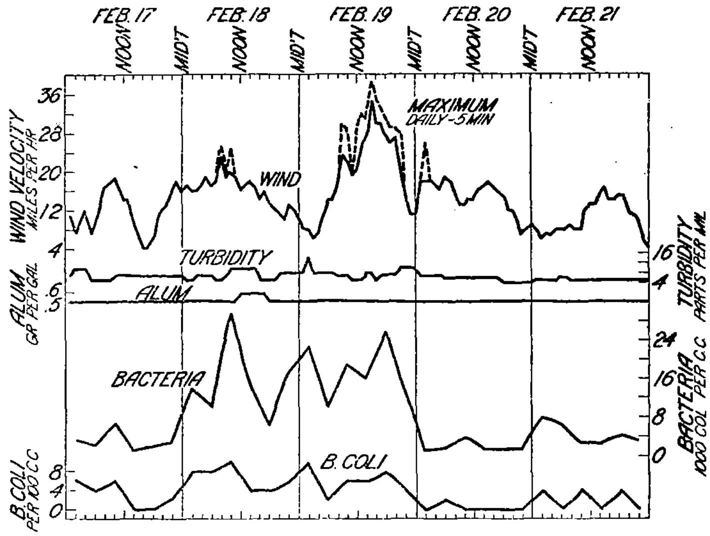

FIGURE 4.—Increased wind velocities when ice is on the lake do not stir up turbidity. *B. coli* did not increase after wind velocities of 38 miles per hour on Feb. 19, 1928

Proof of the preceding may be seen from past records of winds and water levels. The influence of wind velocity and directions on lake levels is such as to cause the two ends of the lake to differ in level as much as 12 feet. The storm of October 20, 1905, displayed an extreme case of this kind. (Fig. 6.) Wind directions and velocities are plotted by hours for Buffalo, Cleveland, Toledo, and Amherstburg. This shows a strong southwest wind with gale velocities in places recorded simultaneously for these cities, and lasting from 1 a. m. October 20, 1905, to midnight, but becoming west wind about noon at Toledo and sometime shortly afternoon at the others. As quickly as the winds had subsided somewhat, or changed from the southwesterly

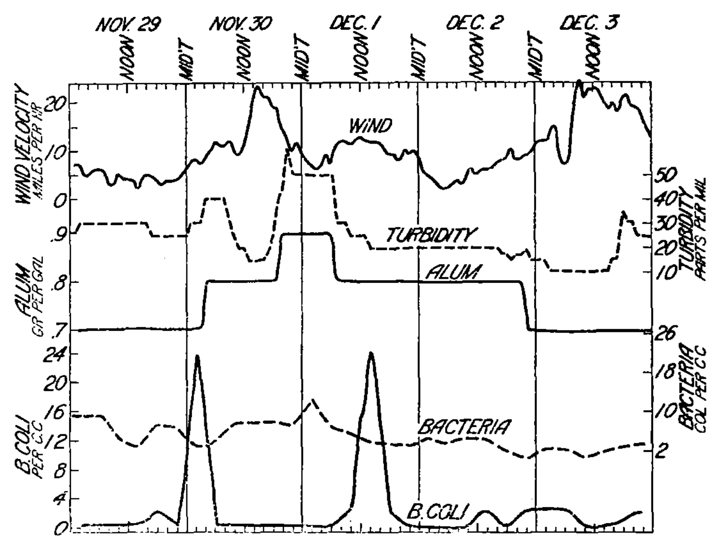

FIGURE 5.—*B. coli* increases are not timed well with increased wind velocity in this chart. It is possible that water "turnover" at this season of the year might bring a general disturbed condition of lake waters and thus explain *B. coli* increases on November 30 and December 1, 1928

[4] Windmill Point at the exit of Fox Creek on the American side of Lake St. Clair has a lake gage station. Amherstburg, Ontario, on the Canadian side and at the mouth of the river has a station at the level of Lake Erie.

direction, the difference in the water levels in the two ends of Lake Erie became less marked. This illustrates the influence of winds on water levels in the lake. Likewise when winds are strong from the east the condition is reversed. This latter situation is the one which builds up water elevations at the mouth of the Detroit River, checks its flow and causes "back flow" into Lake St. Clair since the latter lake is not large or elongated enough to have the same effects.

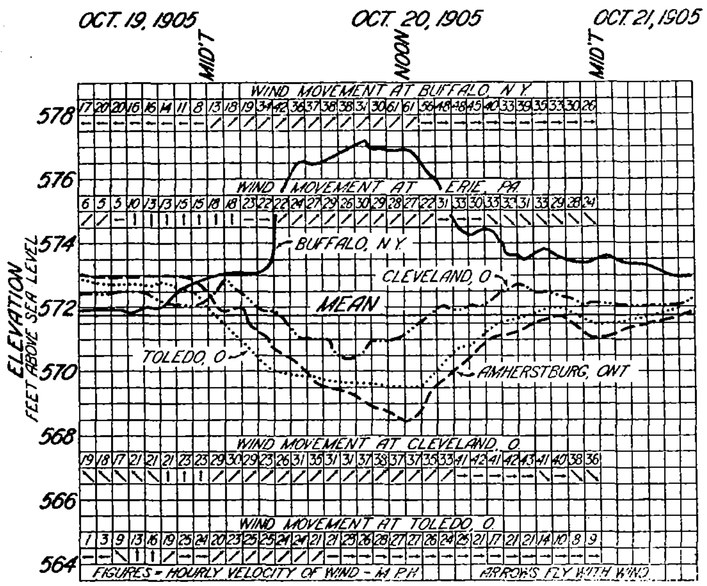

FIGURE 6.—Great differences in water levels at the eastern and western ends of Lake Erie are caused by winds. The level at Amherstburg (mouth of Detroit River) is watched closely by filtration officials. Flow of Detroit River may be slowed up, quickened, or reversed, since the difference in levels of Lake Erie and Lake St. Clair is only 3½ feet

On February 1, 1915, the reversal of the Detroit River occurred. It also occurred on April 10 and 11, 1918, at which time with strong persistent northeast and east winds, Lake Erie was higher than St. Clair for a period of 12 hours. (Fig. 7.) In this last case the lake levels changed back to normal when the wind velocity lowered. Records from the Great Lakes Survey Office show that back flow must have occurred in the past on the following series of dates: February 5, 1909; February 6, 1911; March 21, 1913; January 31, 1914; February 1, 1915; April 10, 1918; and December 5, 1926. G. W. Hubbell, Detroit sanitary engineer, observed that on February 6, 1911, the back flow lasted more than seven hours, and that on this occasion there was a strong east wind, also ice in St. Clair River.[5] He believes that ice served to check the inflow, thus favoring back flow of the Detroit River. Back flow is likely to occur once in four years, according to Hubbell's estimate.

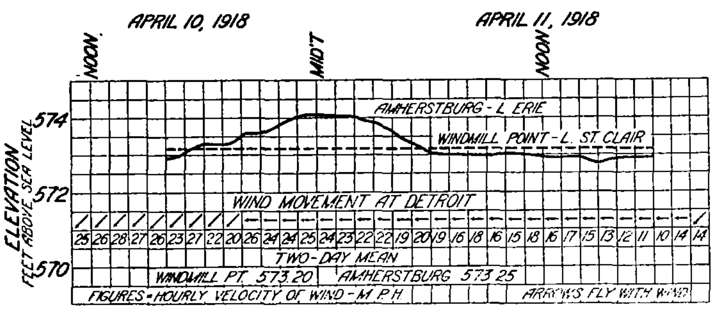

FIGURE 7.—Detroit River must have back-flowed for 10 hours during this storm. When the wind velocity decreased, Lake Erie fell. Notice that the level of Erie changes more than that of St. Clair

The results of back flow are not fully known. The whole question was first called to attention in 1916 by Hubbell and the international joint commission. No definite increases in typhoid have been associated with back flow, though several periods of intestinal disorders among the people have been attributed to the drinking water at these periods. Hubbell believes that sewage remains near the shore in back flow, as in regular downflow of the river, thus not reaching the water intake in great quantities. It is noted that the amount of sewage sent to the lake and river is increasing rapidly every year. The wastes of a population of approximately 800,000 people reached this outlet in 1918, while in 1930 there were 1,600,000 persons contributing sewage to the Lower Straits. The possibilities of winds combining with other influences in polluting the water supply are very great at present, and only great vigilance in treating and filtering of the water can insure a potable supply for Detroit if the intake remains in the present position.

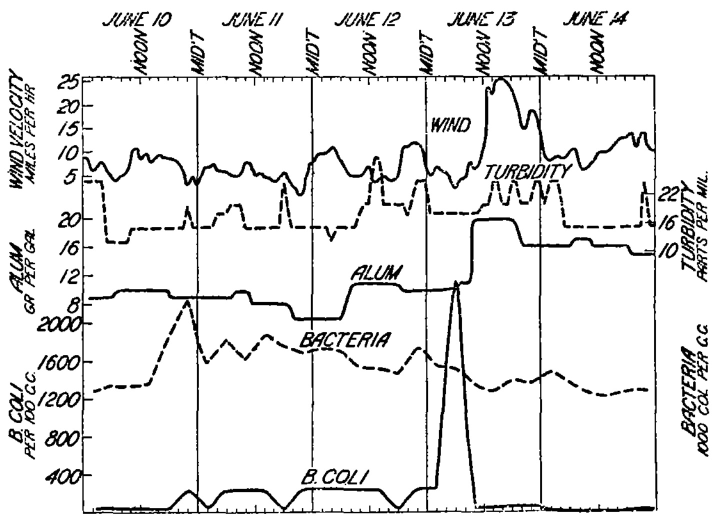

FIGURE 8.—A tremendous and sudden increase in B. coli not associated with increased wind velocity, but following closely a period of heavy rains for three days. A flushing out of polluted tributary streams to Lake St. Clair caused this pollution

Rainstorms flush out the small drainage basins into Lake St. Clair above the intake, and bring pollution to the water supply. Fox and Conners Creek basins have given most trouble on this score in recent years because of the location of their outlets only a short distance above the intake. (Fig. 1.) On February 1, 1926, of the 1,000,000 people supplied with the water from the municipal plant 200,000 had intestinal trouble. The Detroit Board of Health made a study of the situation and reported that it resulted from the pollution from the Conners Creek following heavy rains and melting. Weather records show no rain between the 28th and 30th of January, 0.04 inch fell on January 31, and 0.09 inch fell on February 1. There were 2 inches of snow on the ground and 10 inches of ice on the lake. On January 30 and 31 the maximum temperature was above 40° F. and the daily minimum was 2° above freezing.[6] With 0.13 inch of rain falling on frozen ground, and a melting snow and ice for two days, the situation preceding the intestinal trouble developed. Filtration records are incomplete for this period, and it is interesting to note that an additional chemist was employed immediately after.

[5] Hubbell, G. W., Report on Sewage of Detroit River, p. 16.

[6] Engineers Metcalf and Eddy estimate 0.03 inch of rain in 24 hours, sufficient to cause run-off from Fox and Conners Creeks.

The storm of June 10, 1928 shows a very high *B. coli* count immediately after heavy rains which flushed out tributary streams to the lake. (Fig. 8) *B. coli* rose past the 2,400 mark per 100 cubic centimeters on the morning of the 13th of June. Winds preceding this disturbance had been low. It is true that high wind velocities did occur in the afternoon of the 13th, but these could not have been a cause, for they followed the *B. coli* increase by 10 hours. The turbidity had been rather irregular on June 10, and 11, and 12. Looking back to the period

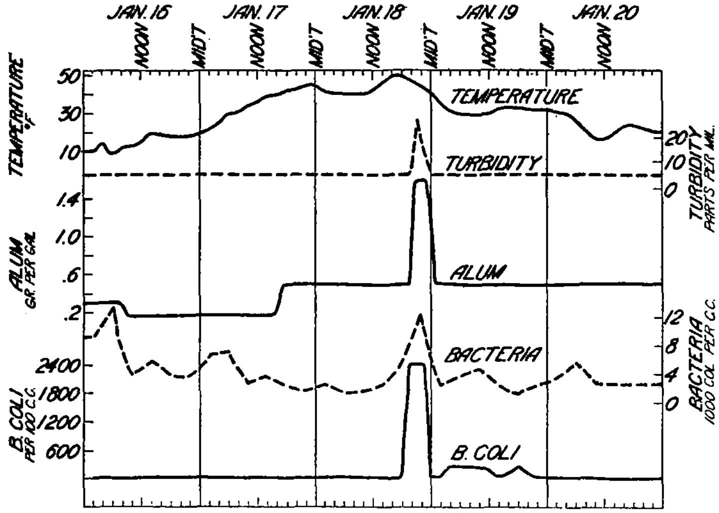

FIGURE 9.—A January thaw. Melting brings polluted ice water from the lake and river shores upstream

from June 4 to 9, it is noted that 1.9 inches of rain fell and that winds were easterly most of the time. Passing vessels may have dumped refuse that reached the intake with a highly polluted water, but it is not likely that this would have kept the *B. coli* count at about 200 per 100 cubic centimeters for more than two days previous to this peak of high pollution. *B. coli* from vessels would have been preceded and followed by water of average *B. coli* count. The high contamination of June 13 is quite clearly the result of flushing out of creeks—probably Conners and Fox—and the varying wind directions and velocities succeeded in bringing it to the intake near the head of Belle Isle. Winds from the south and southwest are more favorable for keeping sewage of Fox and Conners Creeks in the currents on the north shore of the river.

In considering the influences of rainstorms on the water supply, engineers have studied thoroughly the Fox Creek and Conners Creek areas. It was found that a rain of 0.03 inch would produce run-off, and that 96 run-off producing rains would occur in a year, on the average. Fox Creek is dry most of the year when Lake St. Clair stands at elevation 573.3 feet, as in 1926. The filtration plant must be prepared to treat excess pollution at any time, from such a possible source.

A good illustration of a thaw and its consequences in filtration of the water supply is seen in the weather and filtration data for January 16 to 20, 1929. (Fig. 9). For several days before January 16 the temperature had been low, and nothing unusual in the way of alum dose and *B. coli* is observed. Five inches of snow lay on the ground and there were 6 inches of ice on the lake. Beginning with 10° F. at 6 a. m. on June 16, the temperature rose steadily for two days, and reached 50° F. at 5 p. m. on the 18th. There was much melting and water ran everywhere. On January 18, there fell 0.87 inch of rain from midnight to midnight. The temperature dropped to freezing on the morning of the 19th, but practically all snow was gone by that time. Five inches of snow had melted; 0.87 inches of rainfall had run-off over frozen ground; much of the 6 inches of ice on the lake was gone; and ice was running freely in the river. At 9 p. m. on January 18, the turbidity, bacteria, and *B. coli* all rose simultaneously and the alum dose was trebled. The coming of trouble had been anticipated by filtration officials, and pumps were started at the Fairview-Conners station, to lift the storm water into the Jefferson Avenue sewer, to send it southward in the interceptor, and thus prevent it from reaching the lake and water intake. This pumping plan was a part of the arrangement just completed for taking care of the sewage of Fox and Conners Creeks. The Jefferson Avenue interceptor flows along that line and empties into the river a short distance below Belle Isle Bridge. It happened that the Jefferson Avenue sewer was full of its own storm water and sewage, and on January 18 of course, all Fox and Conners Creek flows went directly to the lake above the water intake.[7] The water which reached the filtration plant was black with grease and oil and polluted matter. Heavy filter washing was necessary on January 19, to clean the filter beds, and it was necessary to scrub the filter walls with brooms. Except for slight tastes in the water on the east side in close proximity to the plant, the people of Detroit generally knew nothing of what had occurred. This thaw cost the city a considerable amount in alum, labor, operation of the filtration plant, and above all it taught the public that a $20,000,000 project for intercepting sewage and a large part of the storm waters of Fox and Conners Creeks, to send it down Jefferson Avenue and out to the river at some lower point, must be rushed to completion.

Another thaw occurred on February 27, 1929. (Fig. 10.) It was similar to the one of the previous month just

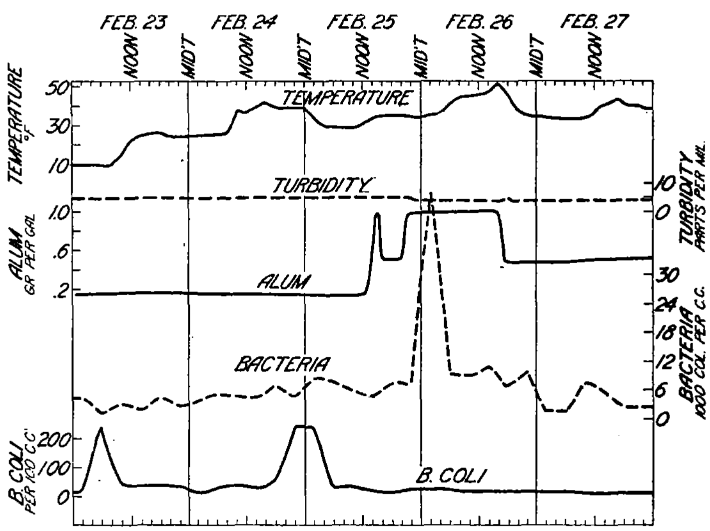

FIGURE 10.—A February thaw. Another close correlation of increased *B. coli* and increased temperature in winter

discussed. There were 4 inches of snow and 14 inches of ice on Lake St. Clair when it came, and 0.28 inch of rain fell to augment the difficulty. Without further detail concerning this thaw, the study of the chart shows that the line for turbidity indicated no change. It failed here to serve as an indicator of pollution for filter operators. Ice was on the lake and foul water beneath it quietly reached the intake without turbidity. The alum application was high on the 25th and 26th and remained fairly high for several days. As a result of

[7] Conversation with officials at filter plant, Jan. 20, 1929.

two thaws coming in two successive months to disturb the water supply, a plan was worked out by which it was required of operators of the diversion pumps at the Fairview station, to notify filtration officials when pumpage had reached the 6,000,000 gallon per day rate. This amount is the maximum for the pumps, therefore sewage and storm waters above that amount must go directly to the lake. Such notification would give filter operators at the plant below, two or three hours to prepare for the coming of impure water.

A thaw quite comparable in its effects on filtration, to the thaws of January and February, 1929, came on January 19, 1928. In fact the thaw is characteristic of the first two months of the year, and will likely occur nearly every year.

Some high pollution which reaches the water intake is without doubt explained by a combination of the factors of wind, temperature, rain, and ice. The storm of March 30, 1928, is one of these. (Fig. 11.) It is noted that water temperature and air temperature rose from below freezing on March 30, to above freezing on April 3, and made the change which probably resulted in much melting, the amount of snow that fell on March 30, was 4.8 inches, and ice in the St. Clair River was opening on the 28th and entirely open on the 4th. Undoubtedly this pollution resulted from a combination of causes. The use of alum at the filtration plant was double the ordinary amount for the three days beginning March 30. The excess alum is estimated to have cost $1,500, exclusive of the attention necessary in its application, and the related costs.

That the weather is the greatest physical factor influencing filtration is shown by the fact that winds stir up the water, thus increasing turbidity and pollution, and necessitating special and careful treatment. Temperature, likewise has its effect through winter thaws; rainfall in flushing pollution to Lake St. Clair and the river; and floating ice by bringing contamination from lake and river sources upstream.

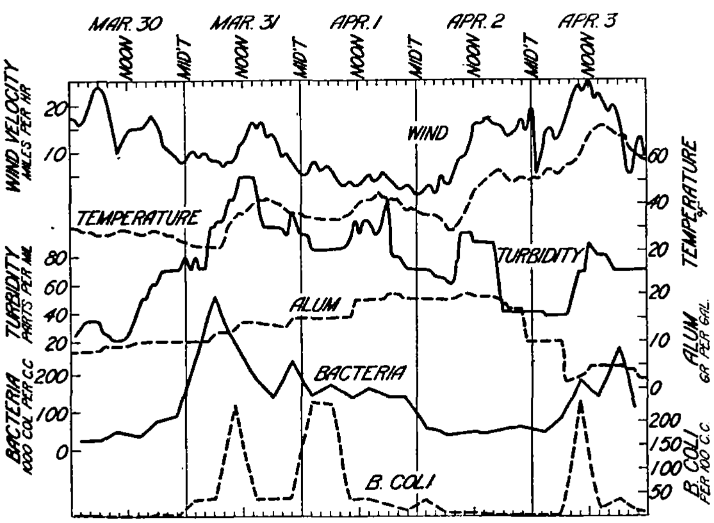

FIGURE 11.—Pollution caused by wind, melting, and floating ice. The first vessel did not go uplakes until April 3, and 4.8 inches of snow fell on March 30.

One other source of polluted water at the Detroit water intake is that from passing vessels. This may be associated with weather, since winds drive the oily and sewage materials, on the surface in the direction that the winds happen to be blowing at the particular time. However, the flow of water at the outlet of Lake St. Clair generally carries water from lake to river regardless of the direction of the wind. The ship channel at the head of Detroit River, follows the Canadian or south side of Belle Isle, and bends to pass on the north side of Peche Isle, keeping close to the international boundary. It passes on the upstream side and within 1 mile of the present intake for the Detroit water supply, and within about one-half mile of the proposed new intake and lagoon at the head of Belle Isle. (Fig. 1.) This nearness to ship channel has been a strong arguing point against the location of a water intake in the vicinity.

On a number of occasions the Detroit River supply has been very high in bacteria and *B. coli* without any evident cause in rainfall, ice, or windstorm preceding it. It is difficult to prove that the source is from passing vessels but this assumption is frequently made, and it is based on good grounds. The disturbance of October 23, 1928, in which *B. coli* rose suddenly to 2,400 per 100 cubic centimeters on the afternoon of October 25, is suggestive of contamination from passing vessels. (Fig. 12.) A rainfall of 0.33 inch had fallen on October 22. This will account for the high turbidity of October 23, but as is shown, this turbidity soon fell, consequently it would be expected that *B. coli* would fall. The winds were of no consequence because the velocity never exceeded 14 miles per hour for three days preceding the coming of this polluted water. There was no ice, for the water temperatures were above 50° F., but records reveal that the vessel traffic was heavy on October 24 and 25, with 77 and 80, respectively. Though not conclusively proven, it is highly probable that pollution did come from passing vessels during these two days.

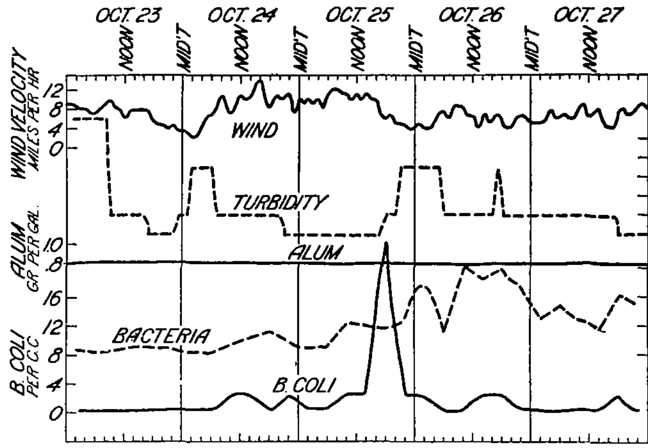

FIGURE 12.—Contamination from passing vessel. Neither ice, rain, nor high wind velocity preceded this sudden rise in *B. coli* on October 25, 1928. However, 77 large lake vessels passed on October 24, and 80 vessels passed on October 25

A summary of the influence of weather on filtration may be made by plotting the daily values of winds, temperature, precipitation, turbidity, plankton, bacteria, *B. coli*, and alum dose and the average daily gallon run per filter at the filtration plant for a year, coordinately, and noting the relations of the curves to each other. This has been done and appears in the chart form. (Figs. 13 and 14.) The wind velocities are shown to vary from a calm to a maximum of 60 miles per hour in 1927. Only the months of July and August show a tendency not to have a velocity of 30 miles per hour, at least once in the month in both 1927 and 1928. April and December have peaks of high velocities both years. The turbidity peaks of the year come in spring at the close of March and beginning of April, and again in the fall at the end of November. These turbidity peaks are closely associated with the temperature, 39° F. at which there is a general turnover of the waters of Lake St. Clair. Undoubtedly the high turbidity in spring is associated

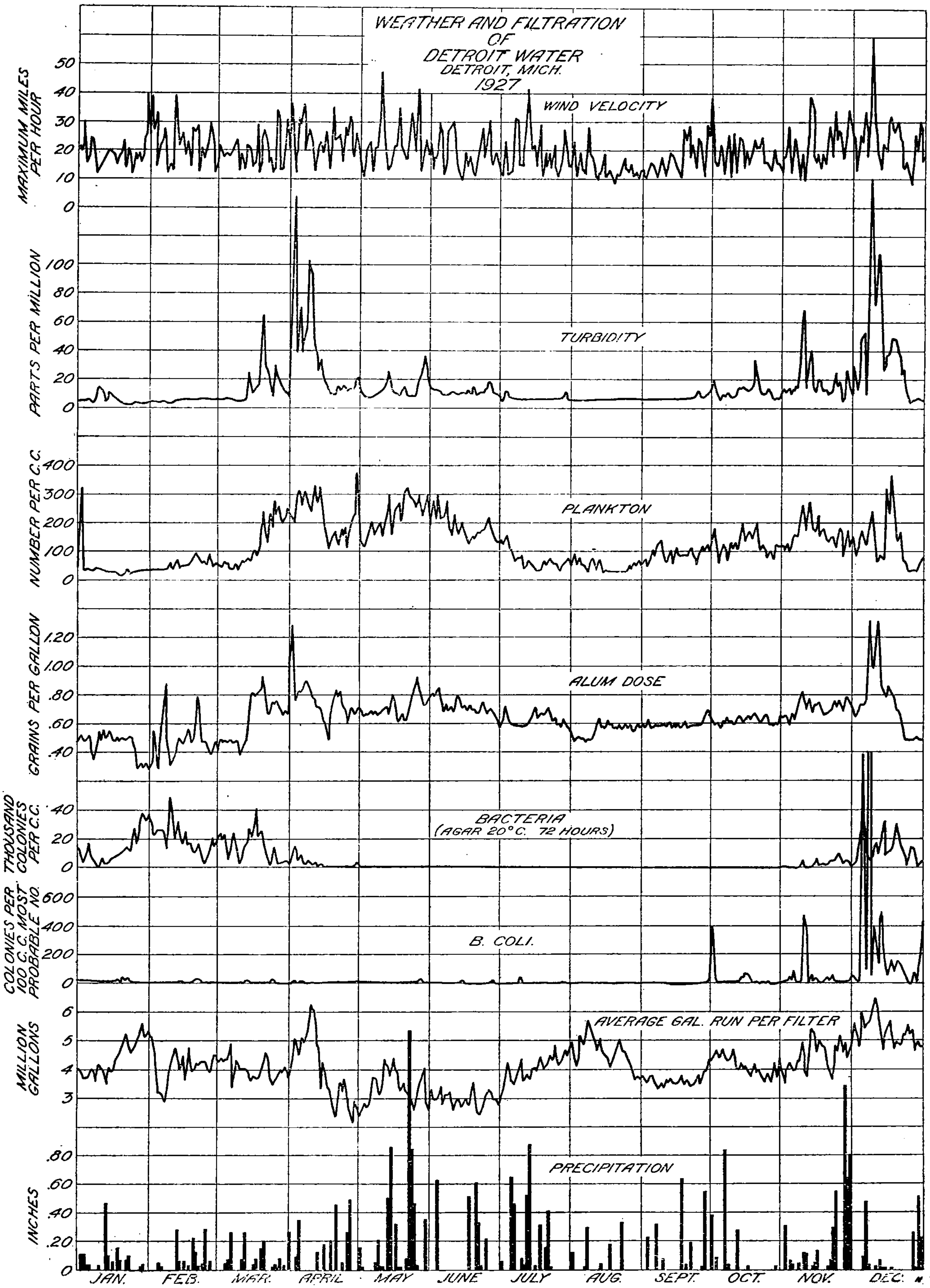

FIGURE 13.—Turbidity, plankton, bacteria, and alum increases come in spring with floating ice and water turnover and again in the late fall with water turnover and storms

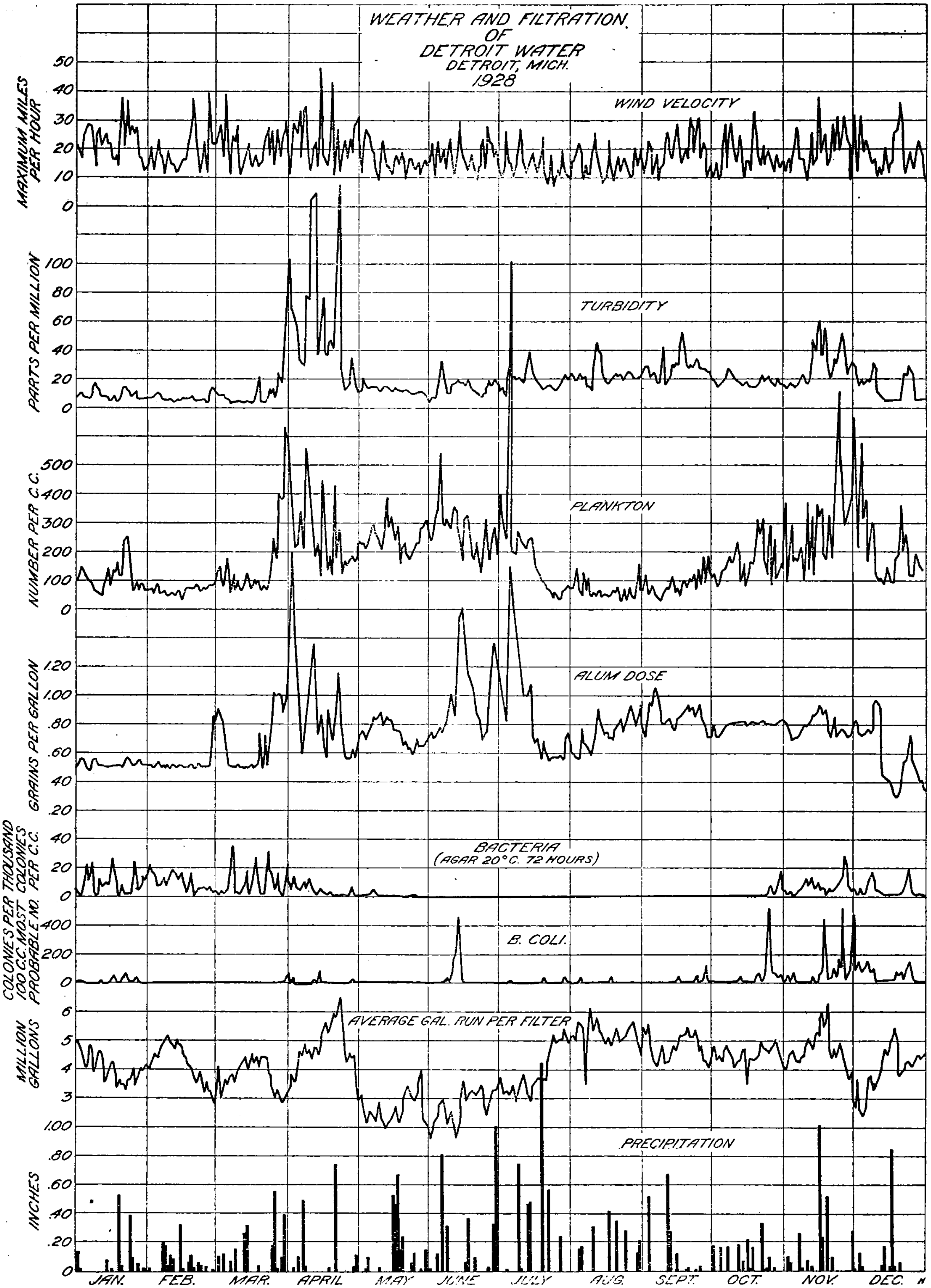

FIGURE 14.—Thaws and water turnover in both spring and fall are evidenced in this chart, as well as increased wind velocity and rainfall as causes for pollution

with the break-up of ice. In both years storms have occurred during the first 10 days of December. High plankton count is fairly well timed with high turbidity. This is expected since part of the turbidity consists of plankton. Thus both are associated with water turnover. High plankton counts extend into June each year probably because of increased light and favorable growing conditions, and show a low count in July and August because of the generally quiet condition of Lake St. Clair. Alum dosage shows the spring and late fall peaks to coincide with high plankton and turbidity rates at the same time. Alum application is generally low in the winter when the ice cover is on Lake St. Clair. At other times alum is closely correlated with turbidity and plankton. In most cases the increased *B. coli* is coordinated with increased wind velocity, increased plankton, or thaws in winter and ice flow in spring. The average daily gallons of water run per filter (between washes) shows that when turbidity and plankton are low as in winter, the filter run is high, and vice versa. Winds, ice, temperature, and precipitation are causes; turbidity, plankton, bacteria, alum, *B. coli* amount, and length of filter run are usually results. Thus the filtration operators have a complex set of factors with which to deal—the weather factors are always present in some form or other.

THE SANTO DOMINGO HURRICANE OF SEPTEMBER 1 to 5, 1930

By F. EUGENE HARTWELL

[Weather Bureau Office, San Juan, P. R., September, 1930]

There was no ship in the Atlantic near enough to report the formation of this storm to the east of the Lesser Antilles, so the first intimation obtainable was in the regular morning reports of the Weather Bureau observers from Barbados to Dominica, each showing a barometer reading only slightly below normal, but a wind circulation decidedly abnormal. The directions ranged from north at Dominica, through northwest and west, to south at Barbados. The observer at Dominica also sent, in addition to his usual code report, "evidences of approaching hurricane." Cautionary advice was immediately sent out to the area from Barbados to St. Thomas, and special observations requested.

At noon communication with Dominica had already ceased, but fortunately the steamship *Lady Hawkins* was a short distance to the westward, and her report, together with those of the nearer islands, and that of the steamship *Invella*, which was just west of Guadeloupe, definitely located the center. It was over or very near Dominica at noon of the first. With this definite information to work from, the storm track was plotted as passing south of Porto Rico and probably Santo Domingo and Haiti, and advisory warnings issued Monday afternoon accordingly.

While the storm was estimated to be of relatively small diameter, no direct evidence was obtainable of this detail until it had passed over Santo Domingo City on the third. Authentic reports place the destructive diameter at less than 20 miles. Reference to barograph traces will show how rapid was the fall and recovery of air pressure during the storm. Three of these traces were reconstructed from readings taken at short intervals by officers of the steamship *Coamo*, which lay just off the shore at the Dominican capital throughout the storm, of the steamship *Catherine*, which encountered the full fury of the elements just south of Saona Island on the return trip from Santo Domingo to San Juan, and by the observer at Dominica. The fourth is a copy of an actual barograph trace, made by the instrument in charge of Mr. A. Ortori, observer at Santo Domingo. This record was made on a sheet limited to 28 inches, the copy being transferred to a sheet with a 27-inch limit and the record extended to the low limit noted by Mr. Ortori on one of his mercurial barometers, namely, 700 millimeters, or 27.56 inches. On the recovery, with the wind shift from north-northeast to south-southwest, the rain stopped the automatic record. The roof carrying the anemometer installation was damaged when the record had reached 100 miles per hour, some time before the vortex passed. The Pan-American Airways anemometer near by is reported to have recorded up to 180 miles per hour before it was carried away. This instrument is a 4-cup Robinson, so its record must be discounted. Wind velocities, estimated by those acquainted by long experience in these areas, vary from 80 to 100 at Dominica to 150 to 200 miles per hour at Santo Domingo. Where the steamship *Coamo* was lying, offshore, the sea was not so heavy, and the direct damage, aside from water damage to interior fittings, was caused by wind pressure. This was sufficient to break pilot house and cabin windows, and list the ship over to 45° from the perpendicular. Doubtless it was only the active pumping of ballast tanks to the high side which kept her afloat. The steamship *Catherine* suffered relatively more because of being more exposed to heavier seas.

The steamship *Antilles* of the French Transatlantic Line entirely avoided the storm in her 48 hours of maneuvering between Jacmel, Haiti, and Santo Domingo City. Her lowest barometer during the 2d and 3d was 29.67 inches, and she entirely avoided destructive winds.

From available observations the trajectory of this storm was almost a straight line from Dominica to the Florida Straits region. Its small diameter makes the assumption probable that the center passed much nearer the south coast of Porto Rico than would be indicated by parallel effects of a wider storm or than was first estimated in plotting the probable path of this storm. Lowest pressures at San Germain and Guayama were only 29.69 and 29.59 inches, respectively. Lowest at Ponce was 29.74 inches, the difference between that and the San Germain report probably being due to difference in elevation. It was learned several days later that winds of sufficient force to damage plantains and other minor crops prevailed in the extreme southwest of Porto Rico, in the Cabo Rojo district, and mountainous seas ravaged the coast from Humacao to Mayaguez.

The forward movement in its path varied greatly, there being a decided slowing up after it passed Porto Rico. During this part of its path it traveled at less than 8 miles per hour. After passing into the Atlantic to the northwestward it resumed a more normal forward movement, but still in the same general direction.

The chart showing this trajectory, Track No. II, also shows the other two which have been reported so far this season. No. I of late in August, which passed west of Bermuda and thence northeastward to the North Atlantic, and No. III, which was reported but twice, first by a Pan American Airways plane on September 6 near St. Lucia, and again at midnight of the 7th by the steamship *Rhodopis*. This disturbance dissipated before it reached proximity to any land station.